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Modeling and optimization of content-oriented and survivable optical networks

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Agenda

- Motivation
- Research area
  - Network flows
  - Optical networks
  - Routing problems
  - Survivability provisioning
- Recent works
  - Modeling and optimization approaches
  - Realistic case study
- Future works

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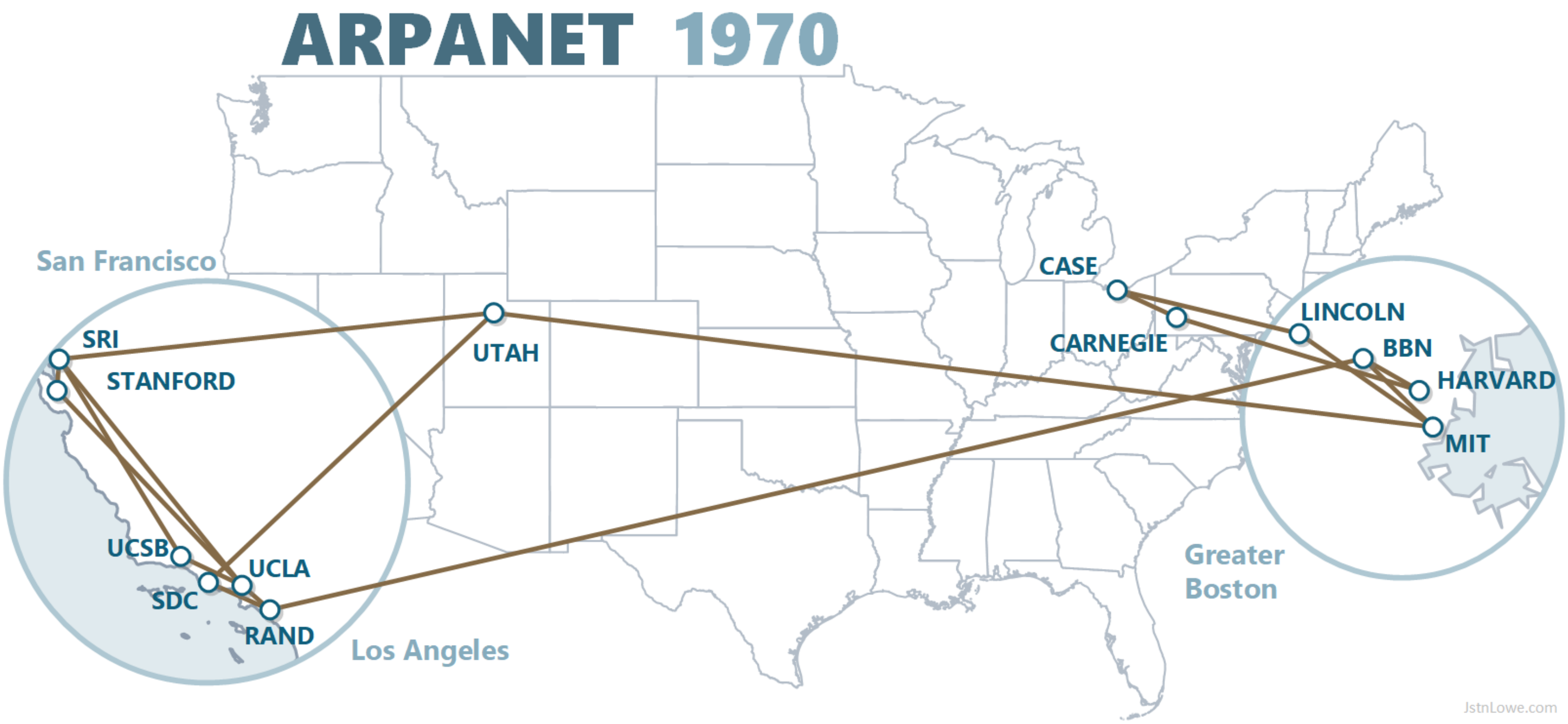
First Wide Area Network



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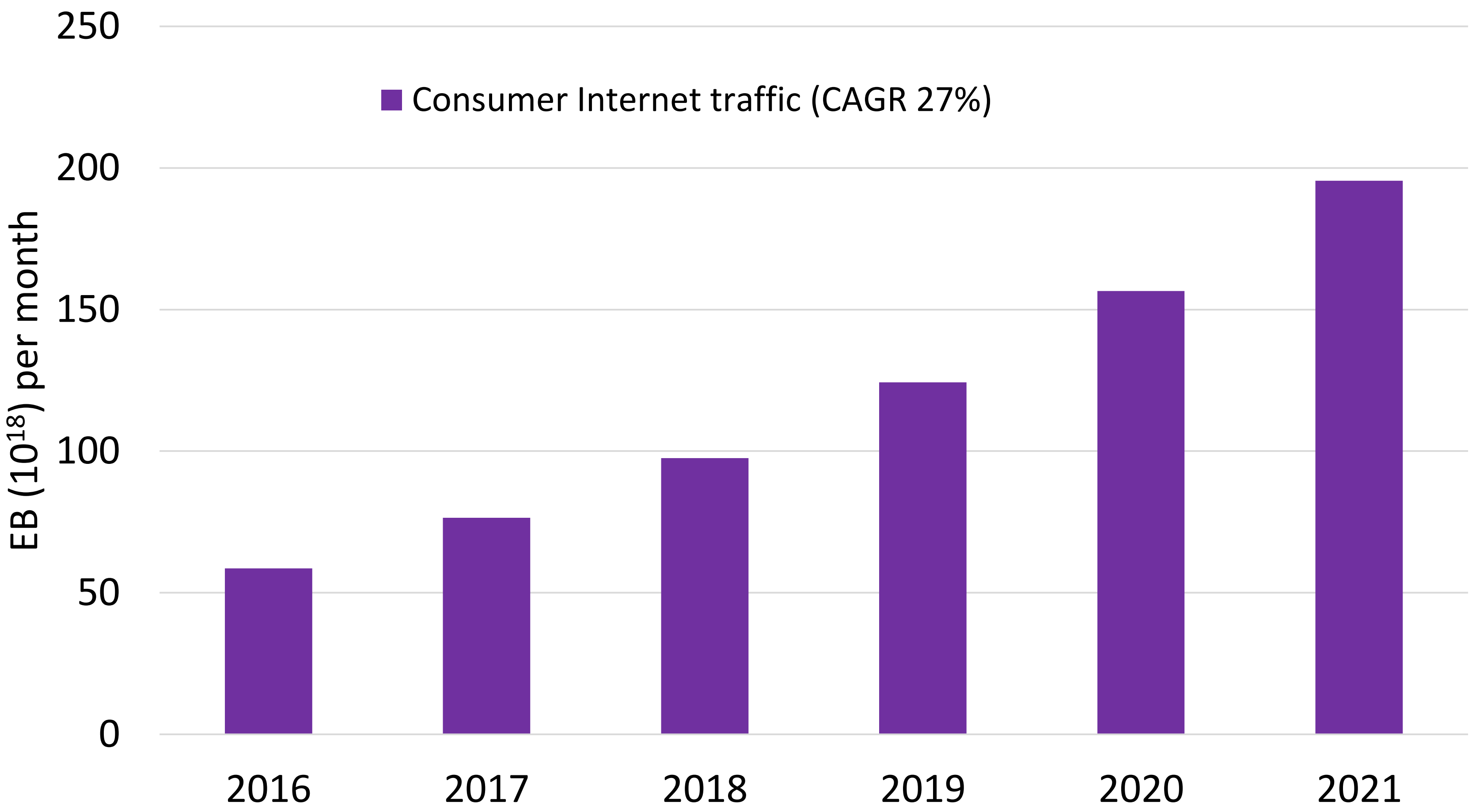
Increase of the network traffic



Source:
[1] Cisco Visual Network Index: Forecast and Methodology, 2016-2021, June 2017

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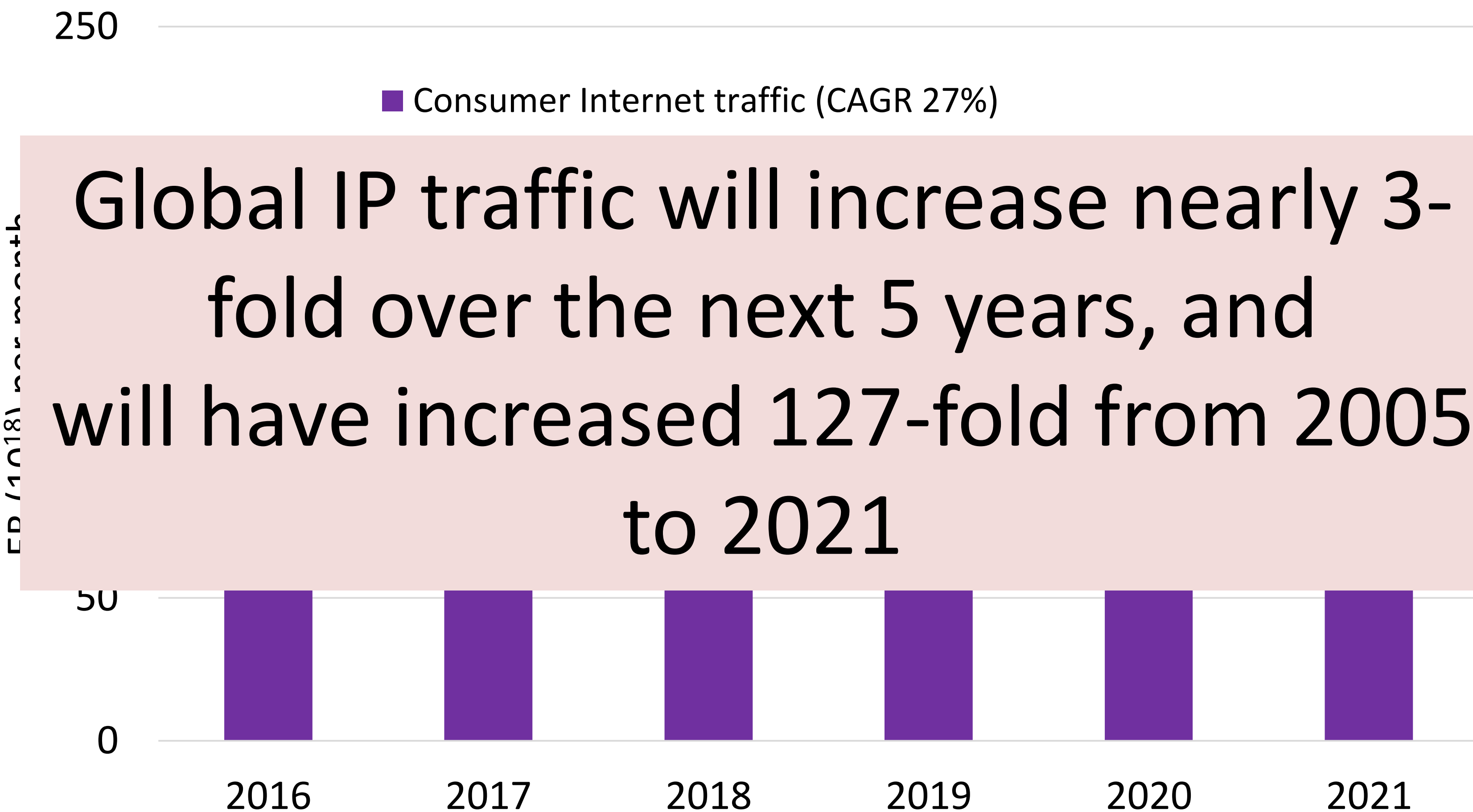
Increase of the network traffic



Global IP traffic will increase nearly 3-fold over the next 5 years, and will have increased 127-fold from 2005 to 2021

Source:
[1] Cisco Visual Network Index: Forecast and Methodology, 2016-2021, June 2017

Increase of the network traffic: example services

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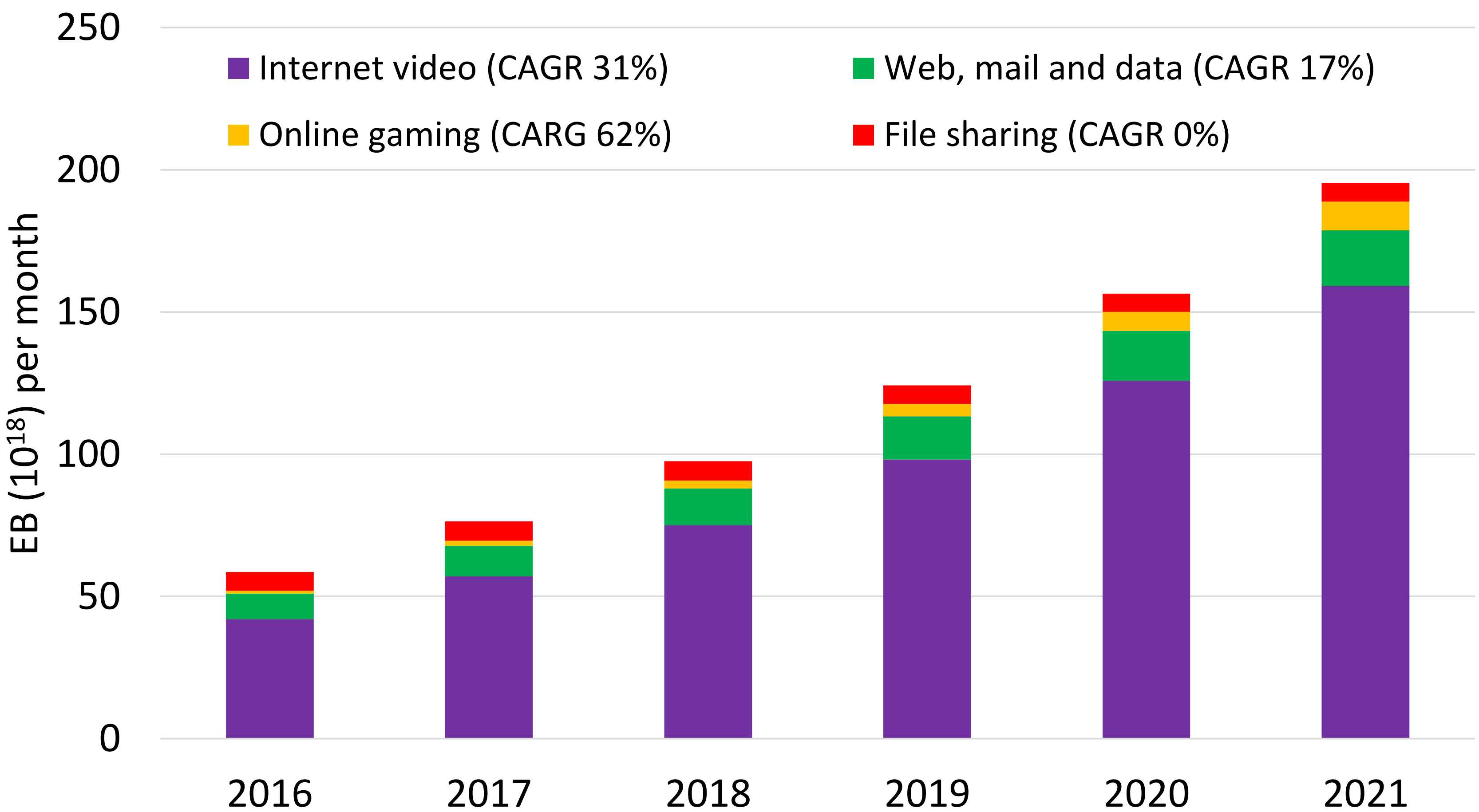

Source:
[1] Cisco Visual Network Index: Forecast and Methodology, 2016-2021, June 2017

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Increase of the network traffic: example services

It would take an individual more than 5 million years to watch the amount of video that will cross global IP networks each month in 2021.

Source:

[1] Cisco Visual Network Index: Forecast and Methodology, 2016-2021, June 2017

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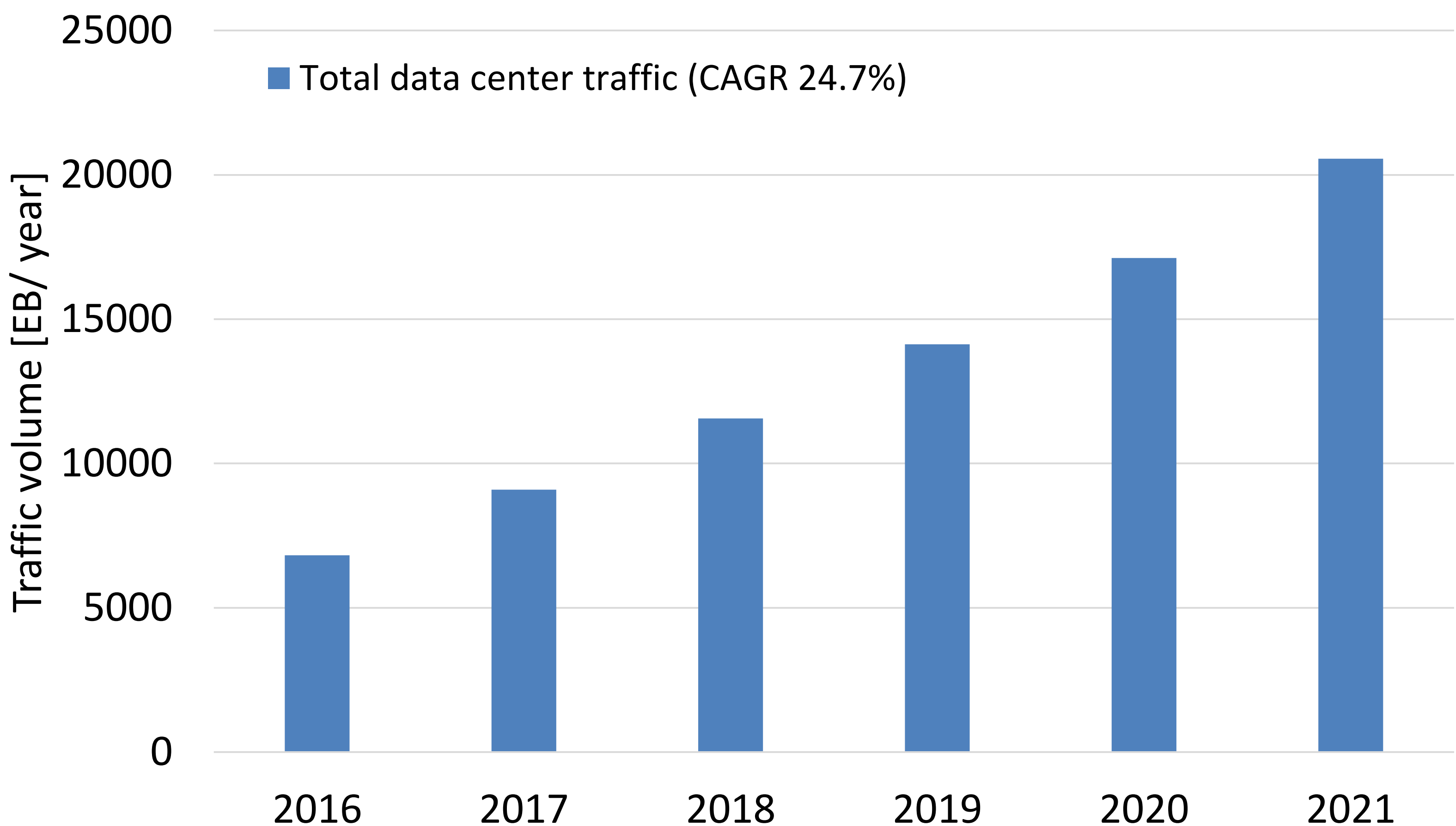
Increase of the network traffic: data center traffic



Source:

[2] Cisco Global Cloud Index: Forecast and Methodology, 2016–2021, 2018

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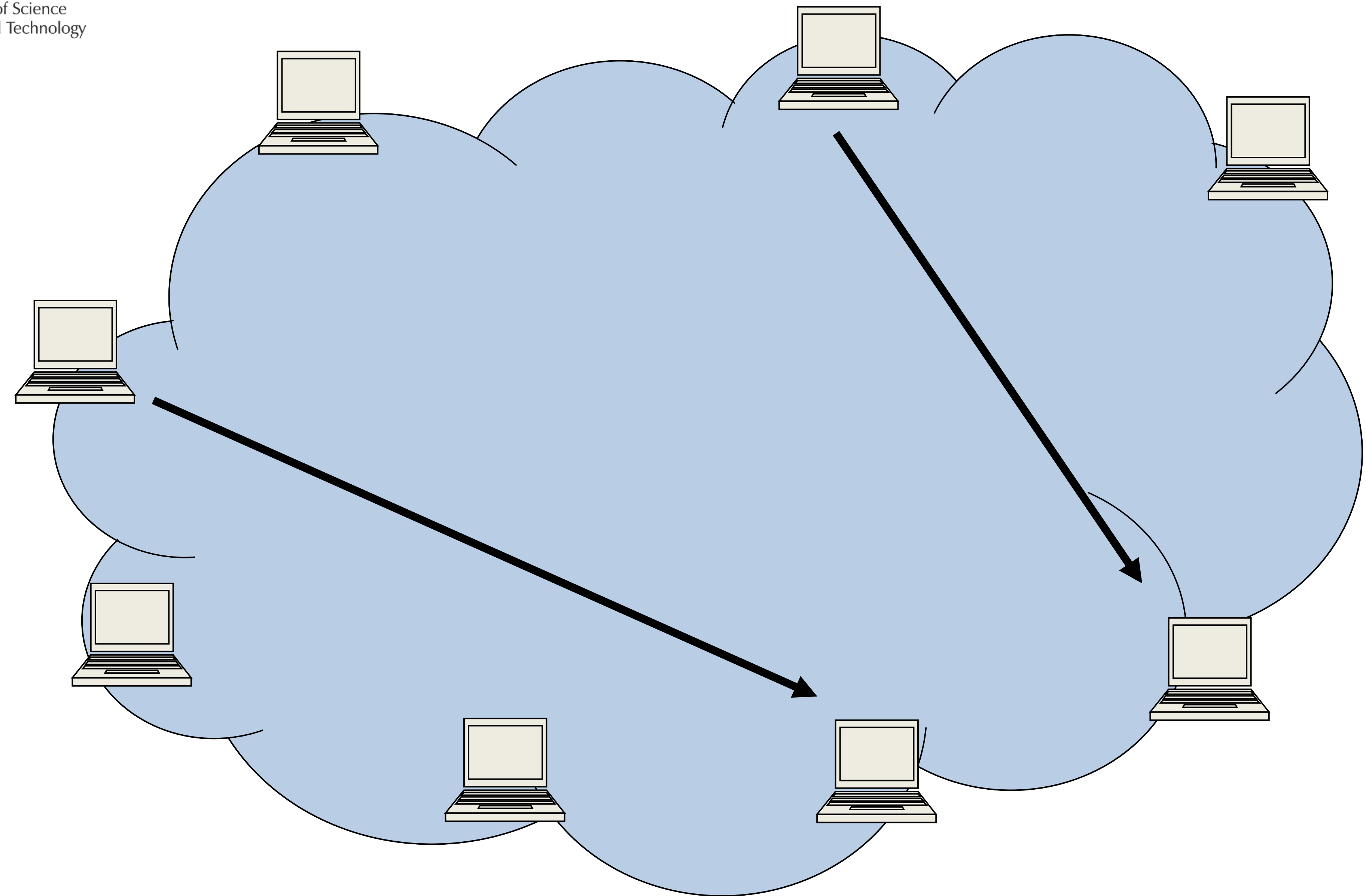
Unicast (one-to-one)



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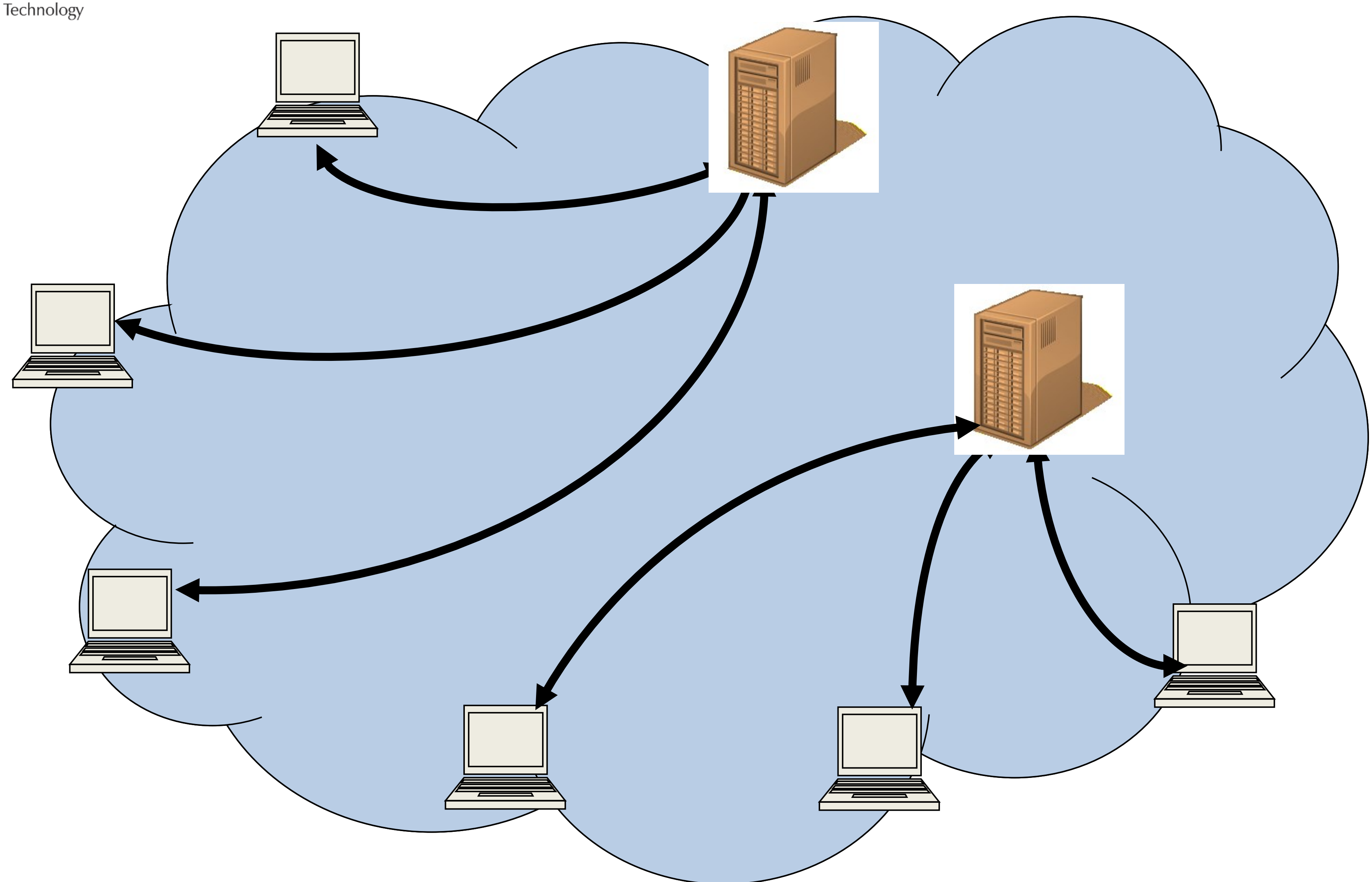
Anycast (one-to-one of many)



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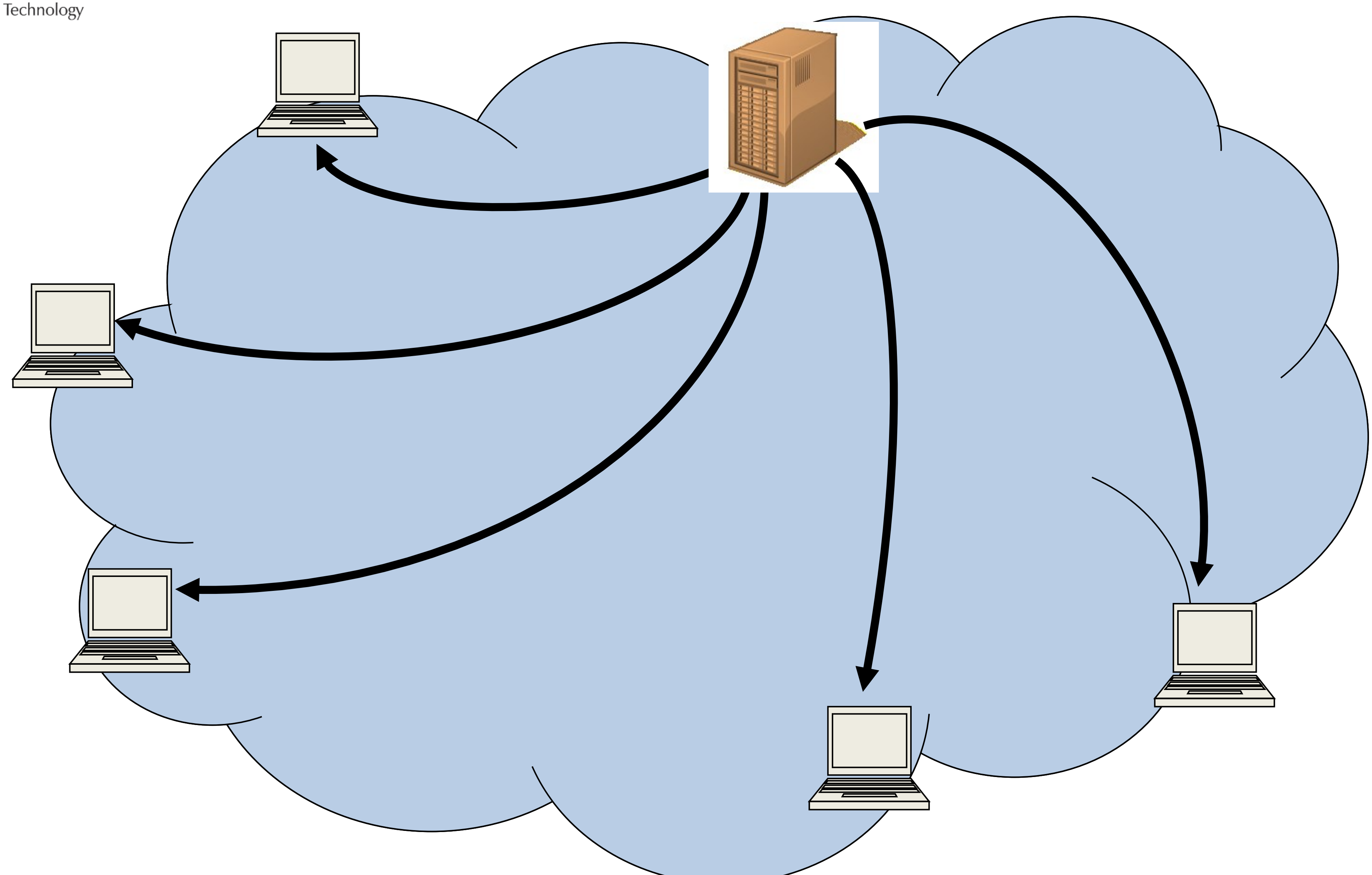
Multicast (one-to-many)



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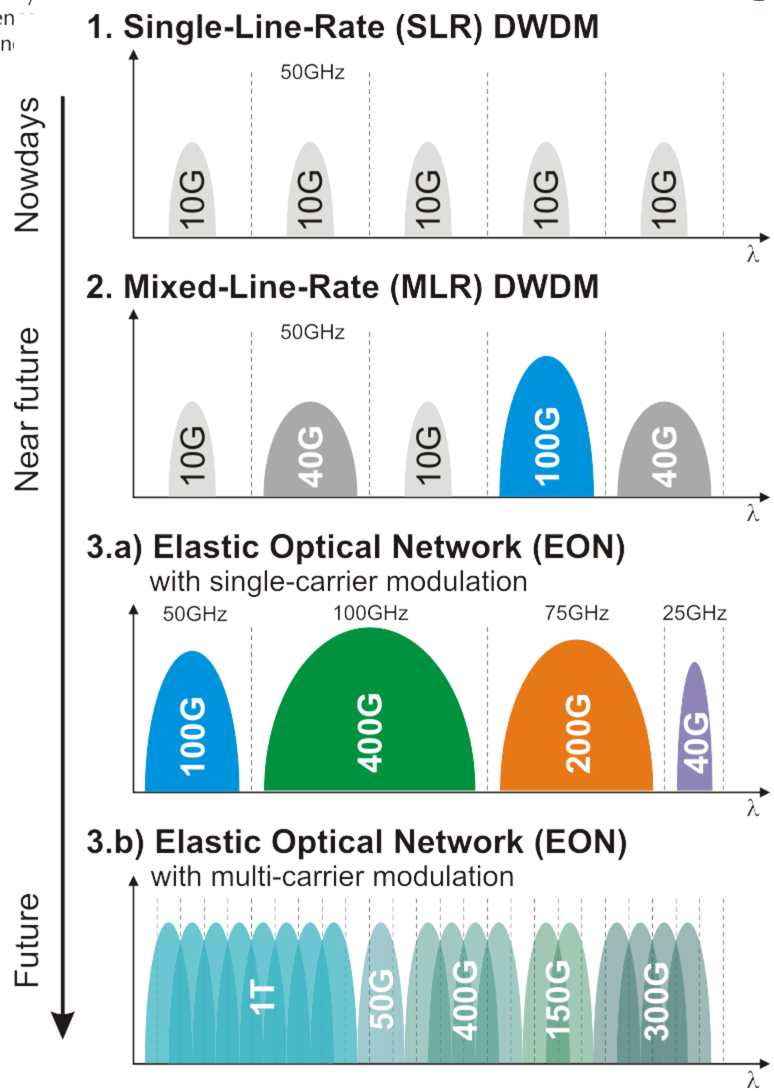
Evolution of optical networks (1)



- Use of a **single-carrier modulation format** (such as NRZ) with a **single bit rate** (10Gb/s) in the entire network and with the **fixed DWDM frequency grid**
  - low Spectral Efficiency (SE)
  - costly (several transponders for large demands)
- Introduction of different **advanced modulation formats** (m-PSK, m-QAM) in the same network
  - \+ improved SE (due to the use of higher modulation levels on shorter paths)
  - \+ 100 Gb/s connection provisioning
- Introduction of **flexible frequency grids** and **Bandwidth Variable Wavelength Selective Switches** (BV-WSS)
  - \+ improved SE (due to the flexible spectrum allocation)
  - \+ 100+ Gb/s connection provisioning
- Introduction of **Bandwidth Variable Transponders** (BV-T) with **multi-carrier tranmission** (such as Optical OFDM)
  - \+ elastic bandwidth provisioning by allocating a number of Sub-Carriers
  - \+ improved SE (thanks to O-OFDM)

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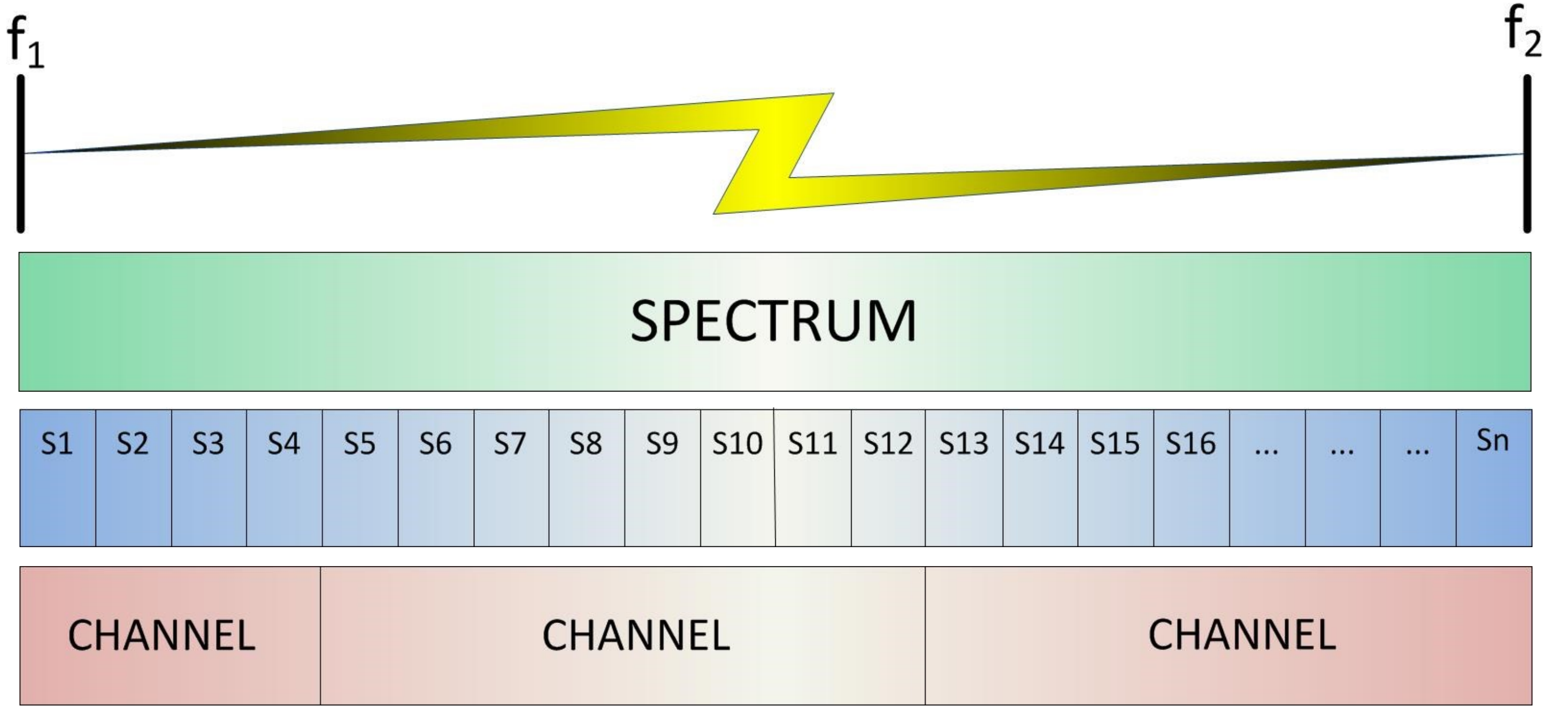
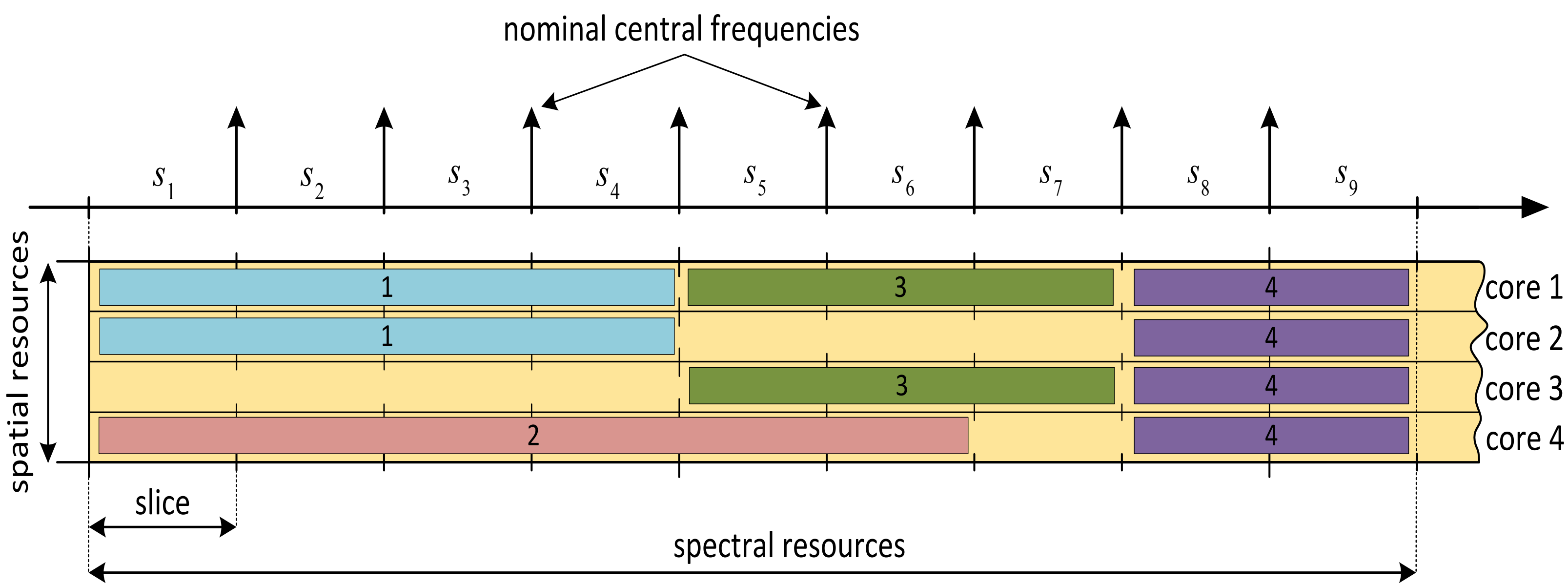
Elastic Optical Network (EON)

Fiber contains *S* spectral slots (slices) in flexible grid



Space Division Multiplexing (SDM)

Fiber contains *k* spatial resources and *S* spectral slots (slices) in flexible grid



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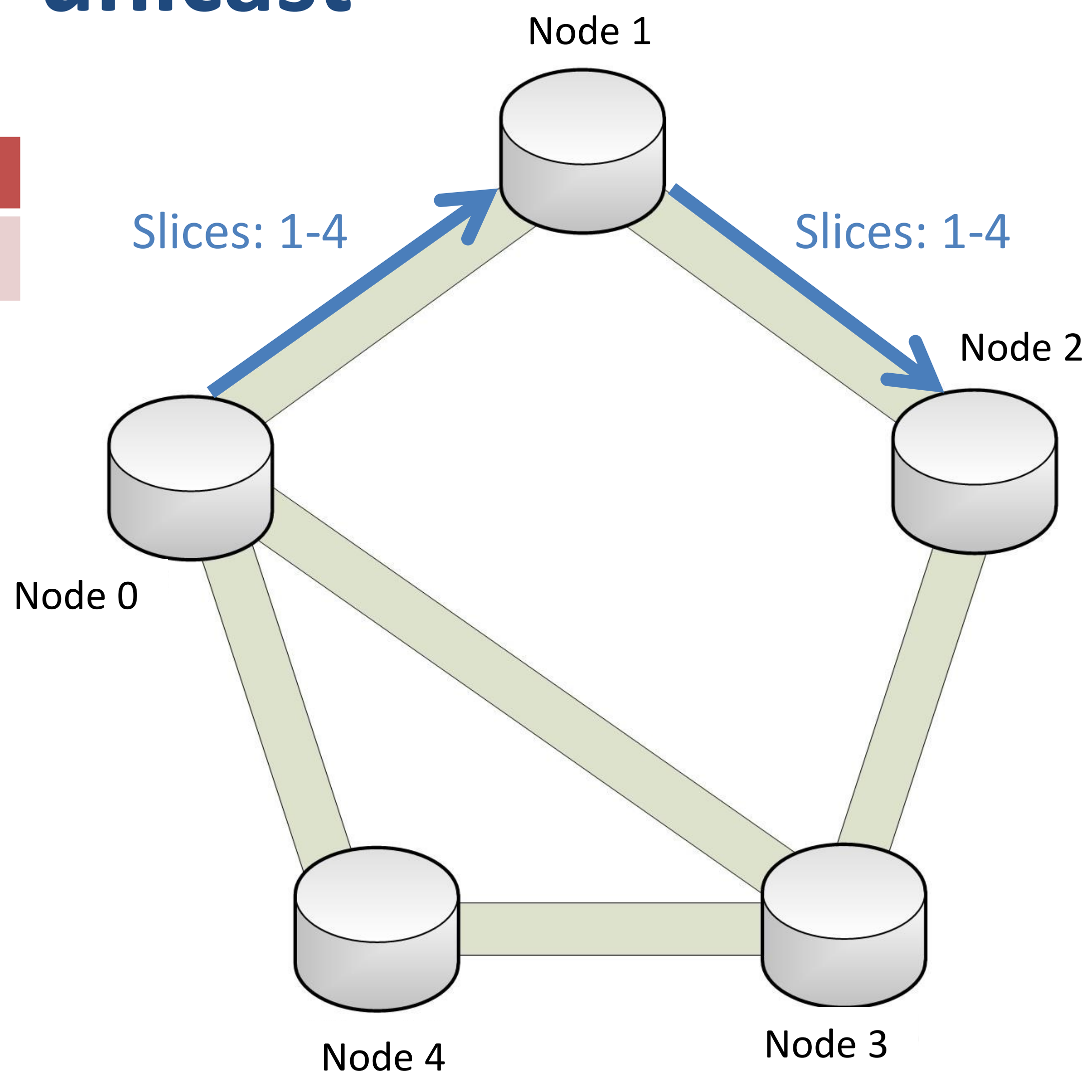
Routing and Spectrum Allocation: unicast

Demand	Route	Slices
Uni	0→2	4



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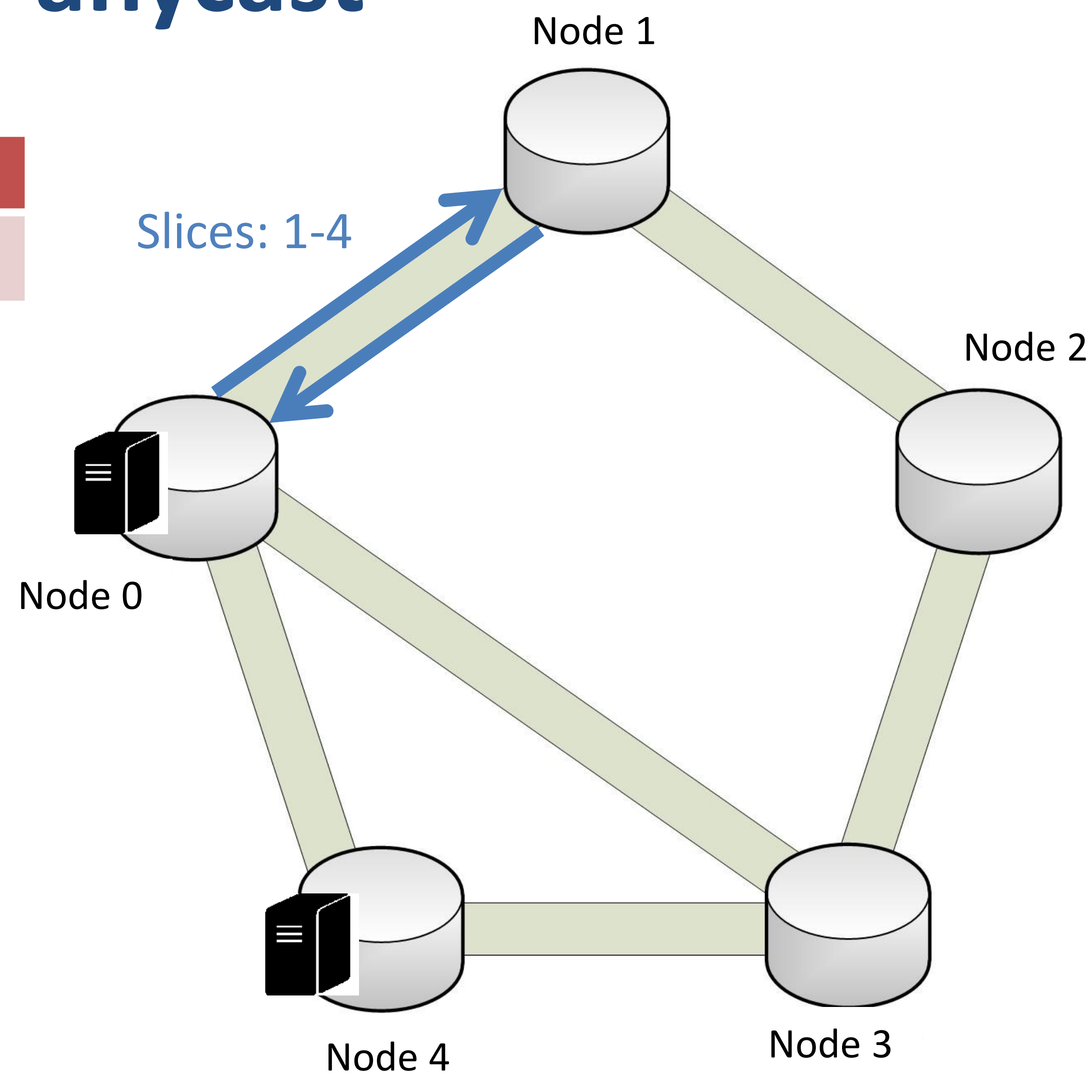
Routing and Spectrum Allocation: anycast

Demand	Route	Slices
Any	1→R	4


Data center



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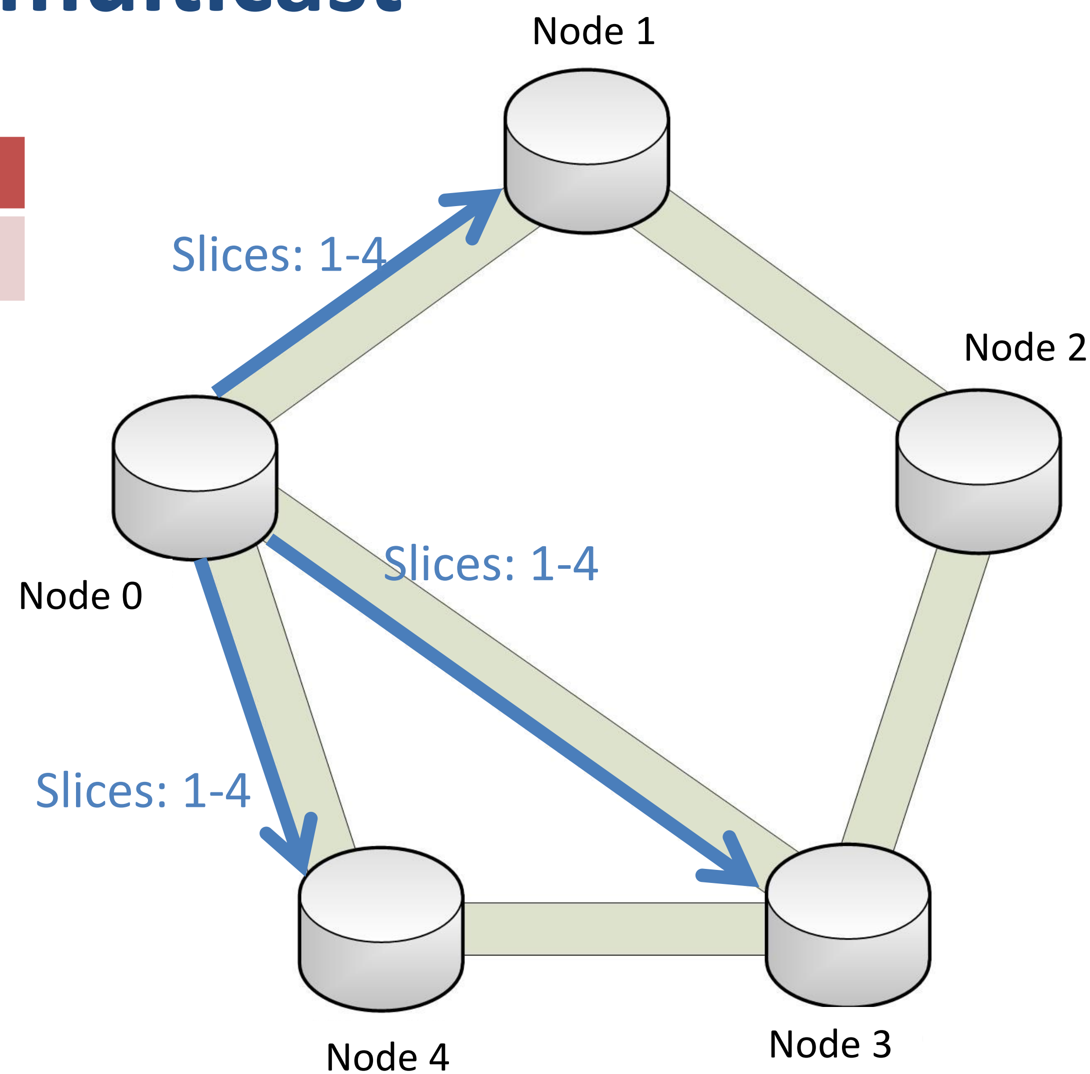
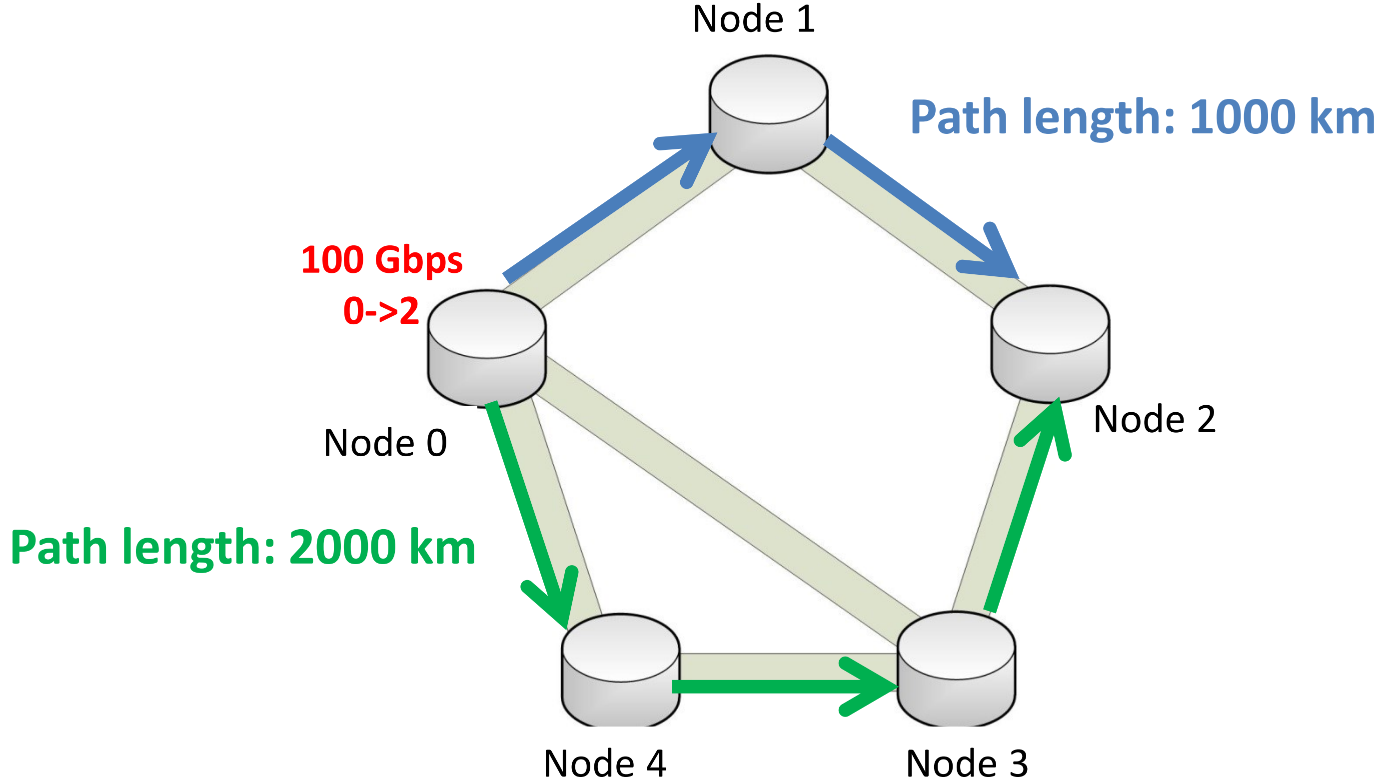
Routing and Spectrum Allocation: multicast

Demand	Route	Slices
Multi	0→1,3,4	4



Distance-Adaptive Transmission



	BPSK	QPSK	8QAM	16QAM	32QAM	64QAM
Spectrum [GHz]	50	25	16.67	12.5	10	8.33
Frequency slices	8	4	4	2	2	2
Regenerators path 1000 km	0	0	0	0	1	1
Regenerators path 2000 km	0	0	1	1	2	3

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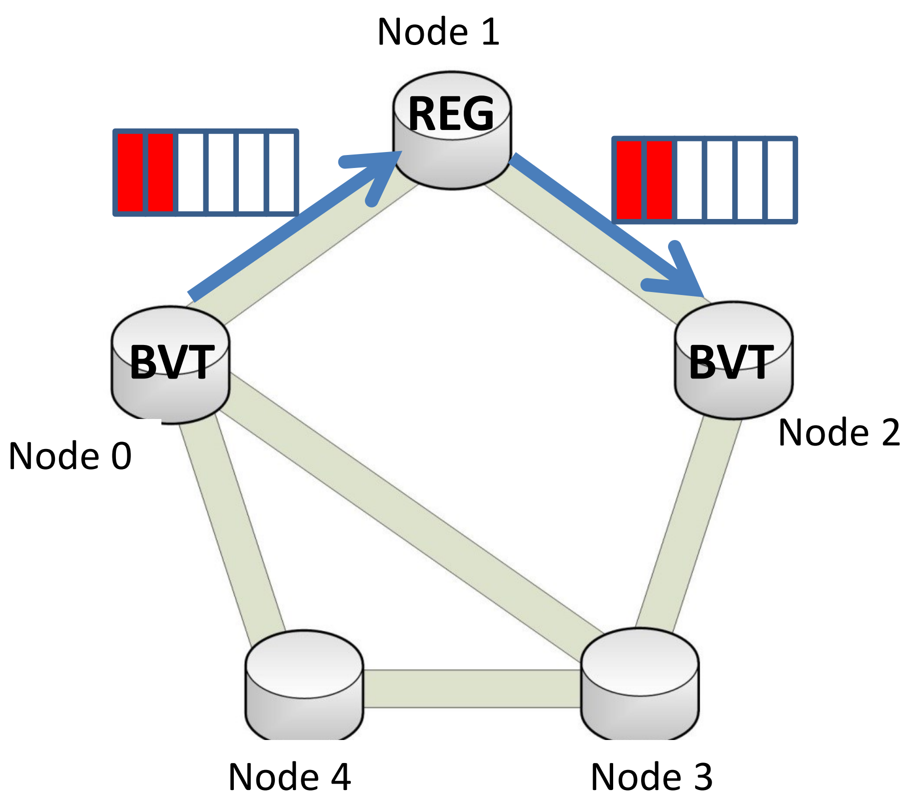
Cost and energy consumption

Cost of:

- Spectrum resources
- Transponders (BV-T)
- Regenerators (REG)

Energy consumption of:

- Transponders
- Regenerators



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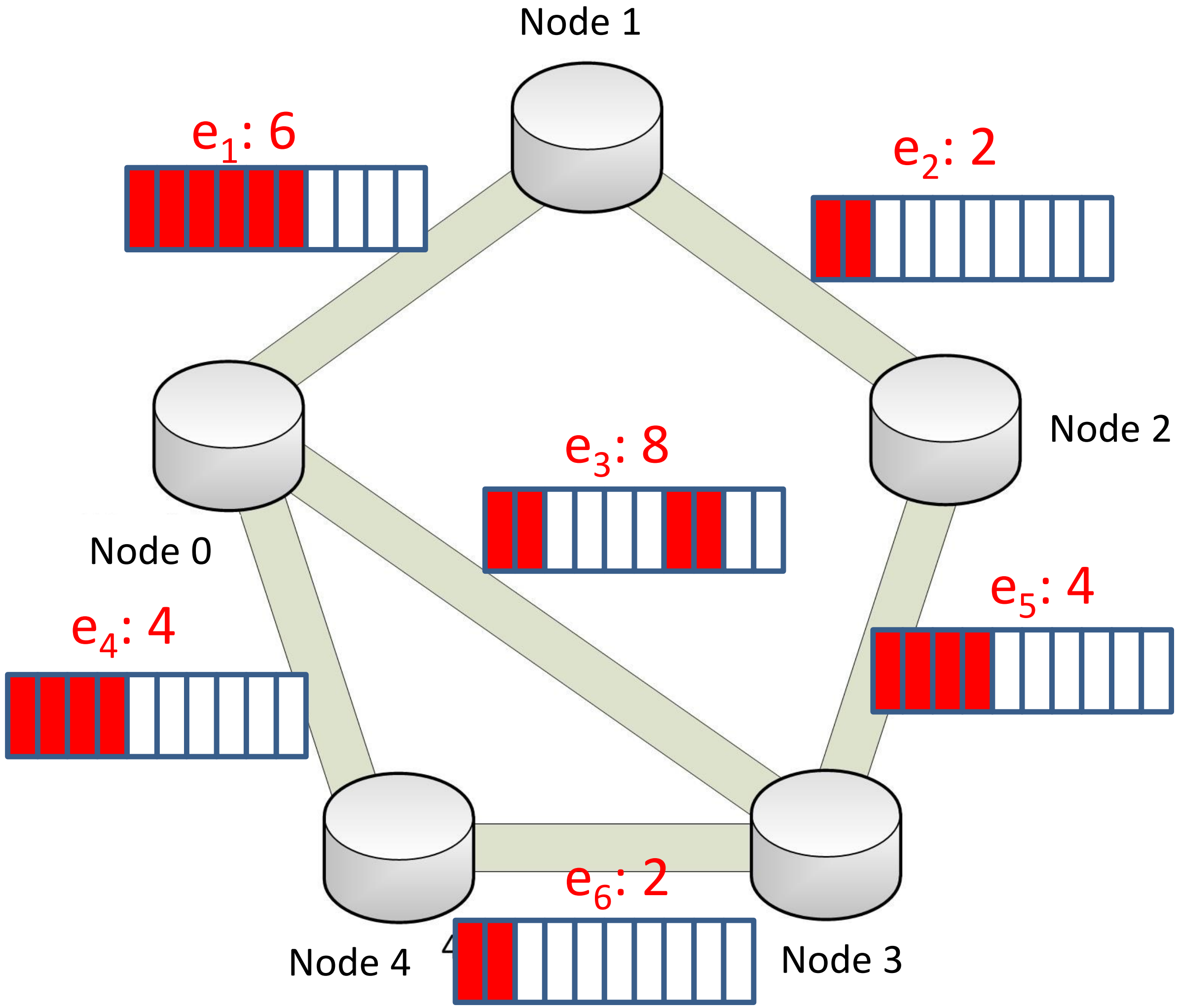
Spectrum usage

Maximum

$$z_{max} = \max_i e_i = 8$$

Average:

$$z_{av} = \frac{1}{|E|}\sum_i e_i = 4.33$$



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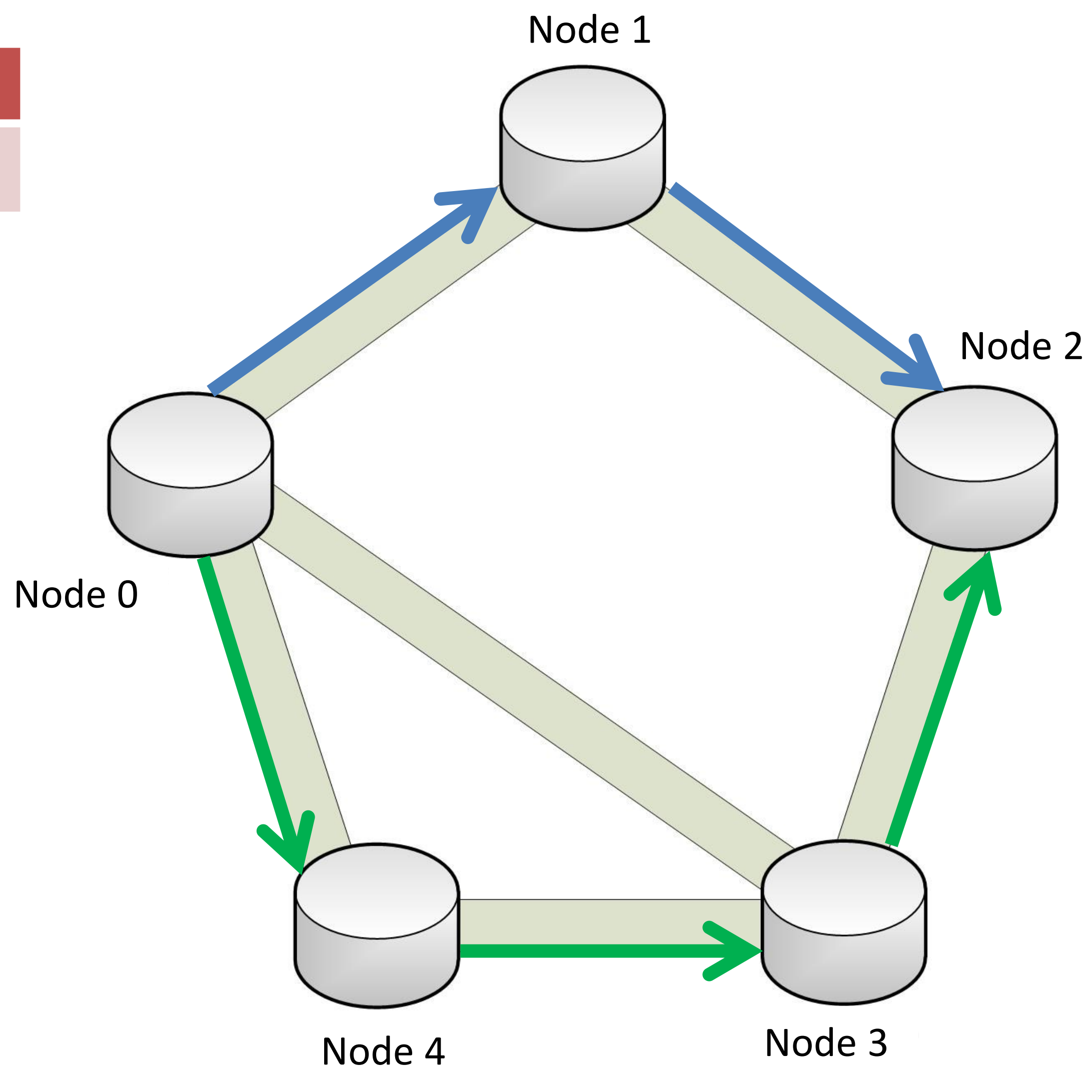
Path-based survivability: protection and restoration

Demand	Route	Volume
Uni	0→2	60 Gbps

- Disjoint paths
- Different modulations
- Channel assignment policies
- Sharing spectrum
- Amount of data to be protected



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Optimization methods

- ILP models (exact method)
- Column generation technique
- Greedy algorithms
- Metaheuristic approaches

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ILP modeling

Comparison of different ILP models of the same problem:

- Channel-based (CB)
- Slice-based (SB)

[2] M. Tornatore, C. Rottondi, R. Goścień, K. Walkowiak, G. Rizzelli, A. Morea, „On the complexity of routing and spectrum assignment in flexible-grid ring networks", Journal of Optical Communications and Networking 7(2), pp. A256-A267, 2015.

[3] R. Goścień, K. Walkowiak, M. Klinkowski, „ILP modelling and joint optimization of anycast and unicast traffic in survivable elastic optical networks", in Proc. Of INOC 2015.

[4] K. Walkowiak, R. Goścień, M. Woźniak, M. Klinkowski, „Joint optimization of multicast and unicast flows in elastic optical networks", in Proc. Of IEEE ICC 2015.

[5] K. Walkowiak, R. Goścień, M. Klinkowski, M. Woźniak, „Optimization of multicast traffic in elastic optical networks with distance-adaptive transmission", IEEE Communication Letters 18(12), pp. 2117-2120, 2014.

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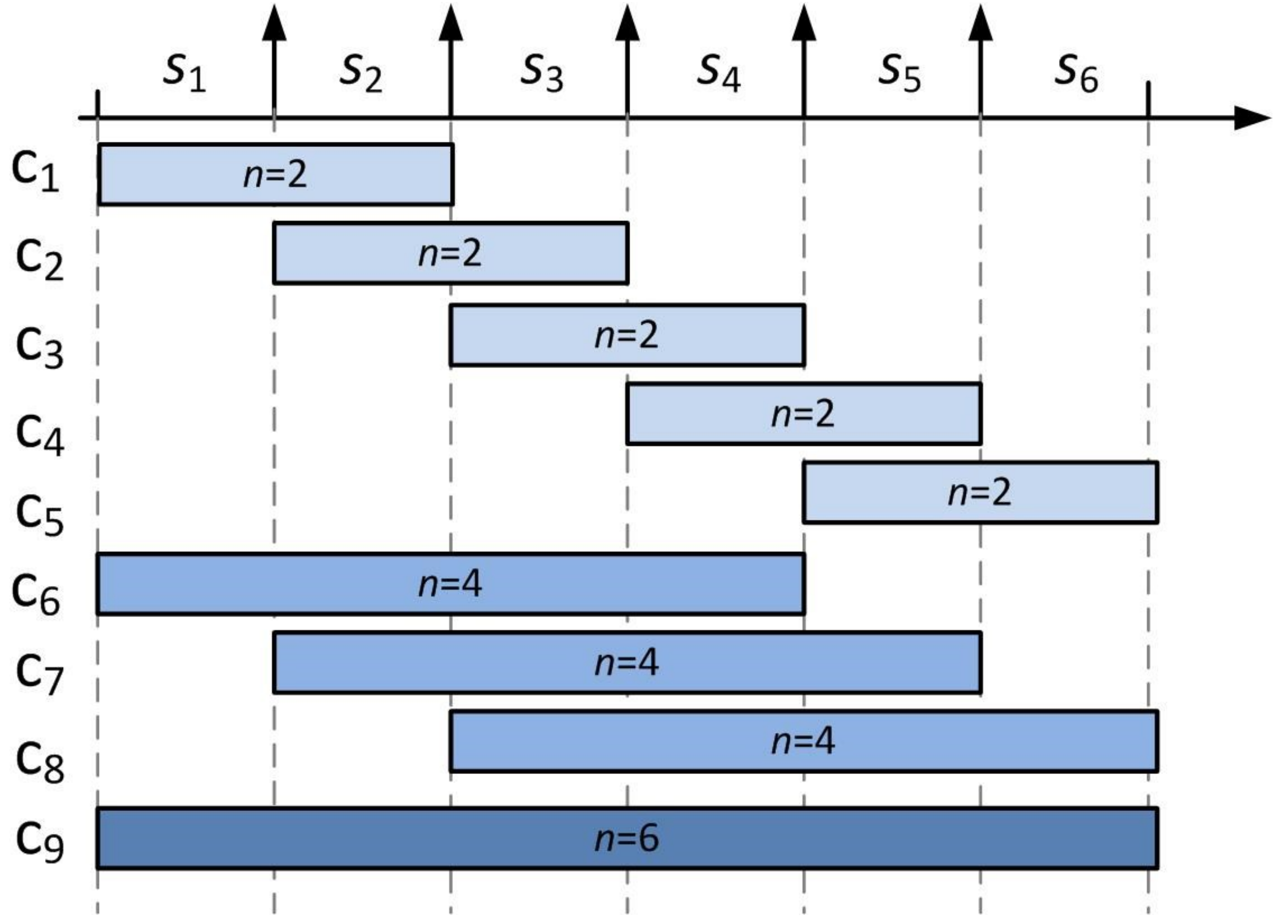
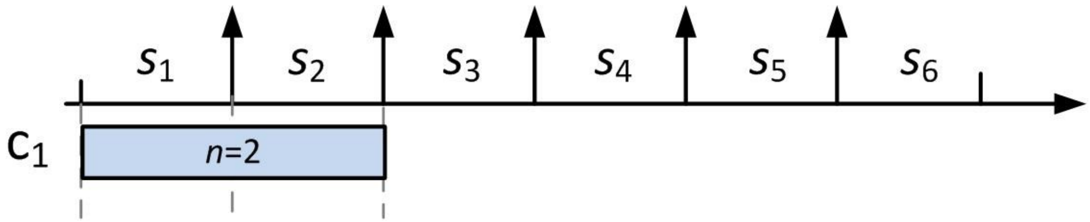
CB: spectrum usage modeling



CB: spectrum usage modeling



C_1 ={first slice index, last slice index, number of slices}

For each traffic demand *d* saves:

x_{dpc}	Information about selected routing structure *p* and frequency channel *c* allocated on this structure

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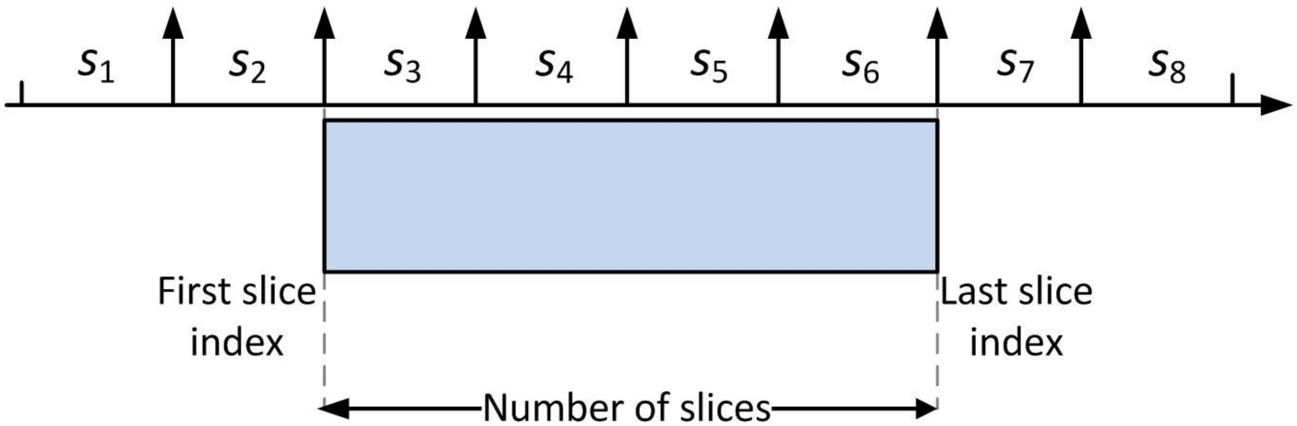
SB: spectrum usage modeling



For each traffic demand *d* saves:

x_{dp}	Information about selected routing structure
w_d	index of the first allocated slice
z_d	index of the last allocated slice

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Column Generation (CG)-based methods

- Column generation is a decomposition method
- Efficient solution approach for problems with a high number of variables

[6] R. Goścień, K. Walkowiak, „A column generation technique for routing and spectrum allocation in cloud–ready survivable elastic optical networks”, International Journal of Applied Mathematics and Computer Science 27(3), pp. 591-603, 2017.

[7] R. Goścień, „On the efficient column generation-based optimization of anycast traffic in survivable elastic optical networks”, in Proc. Of ICTON 2017.

[8] R. Goścień, R Goścień, „On the initialization in column generation for cloud-ready and survivable EONs”, in Proc. Of RNDM 2017.

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Greedy and metaheuristic approaches

- Adaptive Frequency Assignment (AFA) – dedicated greedy method [9]
- Tabu Search [9], [10]
- Swarm intelligence [11], [12]

[9] R Goścień, K Walkowiak, M Klinkowski, „Tabu search algorithm for routing, modulation and spectrum allocation in elastic optical network with anycast and unicast traffic", Computer Networks 79, pp. 148-165, 2015.

[10] R. Goścień, „Tabu search algorithm for routing and spectrum allocation of multicast demands in elastic optical networks", in Proc. Of IDEAL 2015.

[11] R. Goścień, „Two metaheuristics for routing and spectrum allocation in cloud-ready survivable elastic optical networks", Swarm and Evolutionary Computation, 2018, in press.

[12] R. Goścień, M. Lozano, „Artificial Bee Colony for optimization of cloud-ready and survivable elastic optical networks", Computer Communications 128, pp. 35-45, 2018.

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Design of content-oriented and survivable network

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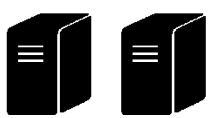
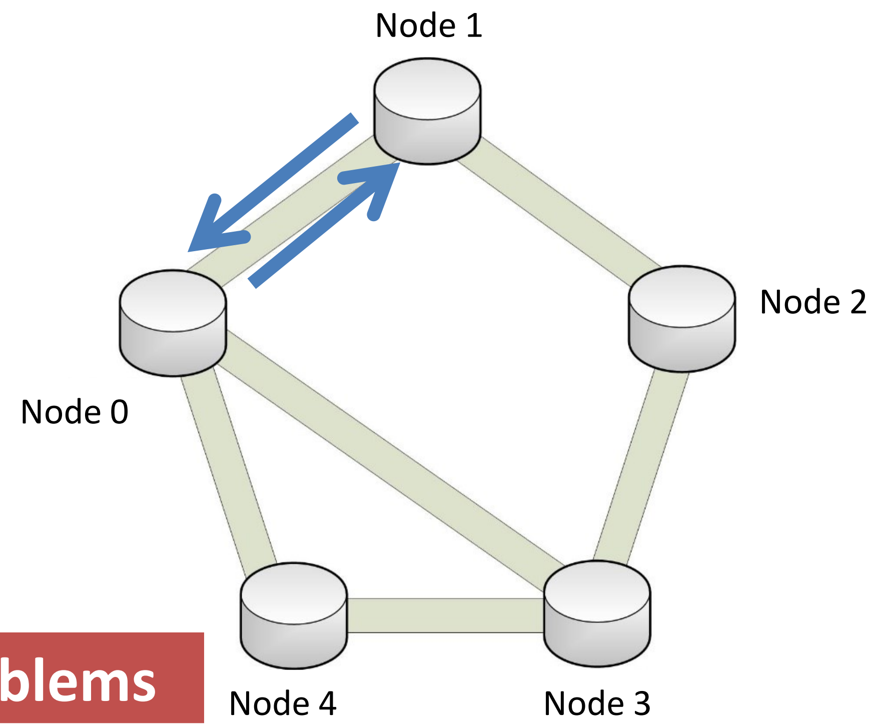
Demand	Route	Volume
Any	1→DC	100 Gb/s
Any	3→DC	350 Gb/s
Uni	2→4	200 Gb/s
…	…	…





Joint problem	Two subproblems
DC location **and** routing	1. DC location 2. Routing

[13] R. Goścień, K. Walkowiak, „Modeling and optimization of data center location and routing and spectrum allocation in survivable elastic optical networks", Optical Switching and Networking 23, pp. 129-143, 2017.

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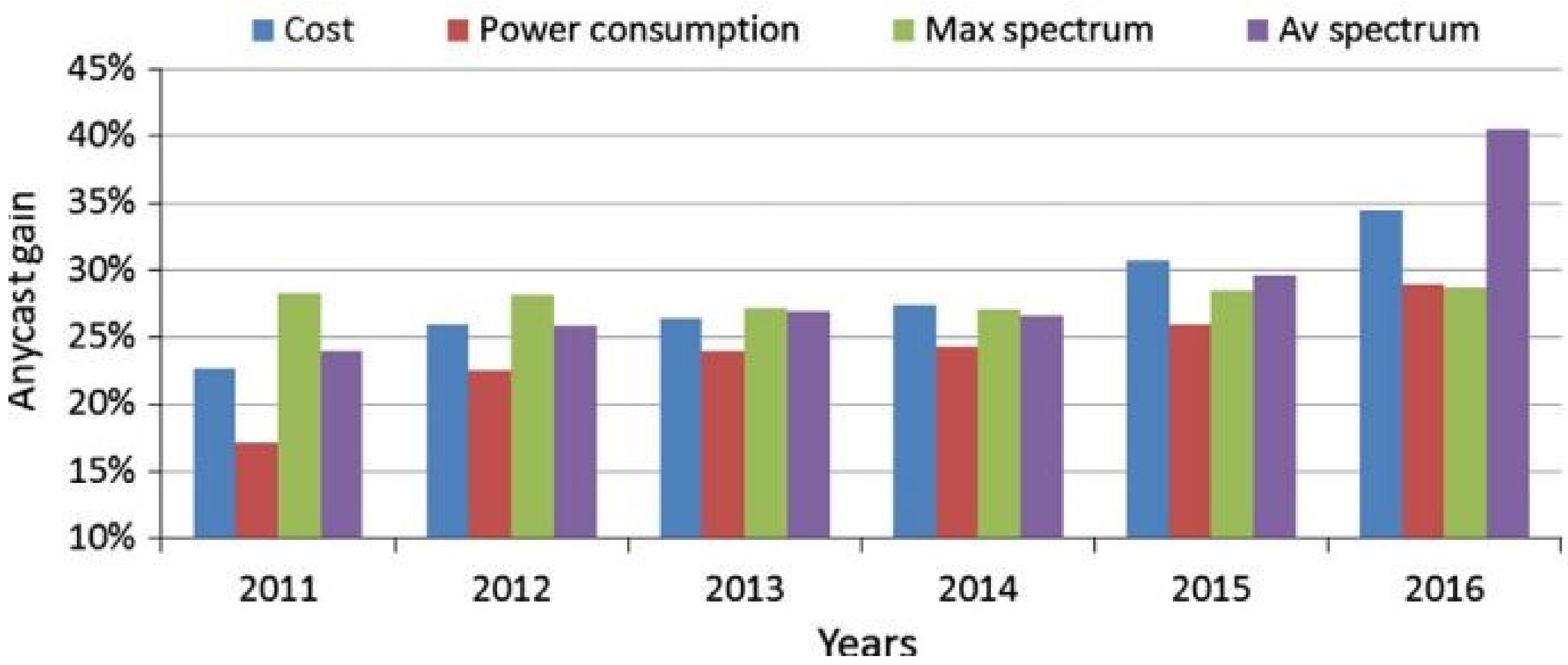
Benefits of anycasting in EONs



[9] R. Goścień, K. Walkowiak, M. Klinkowski, „Tabu search algorithm for routing, modulation and spectrum allocation in elastic optical network with anycast and unicast traffic", Computer Networks, vol. 79, pp. 148-165, 2015.

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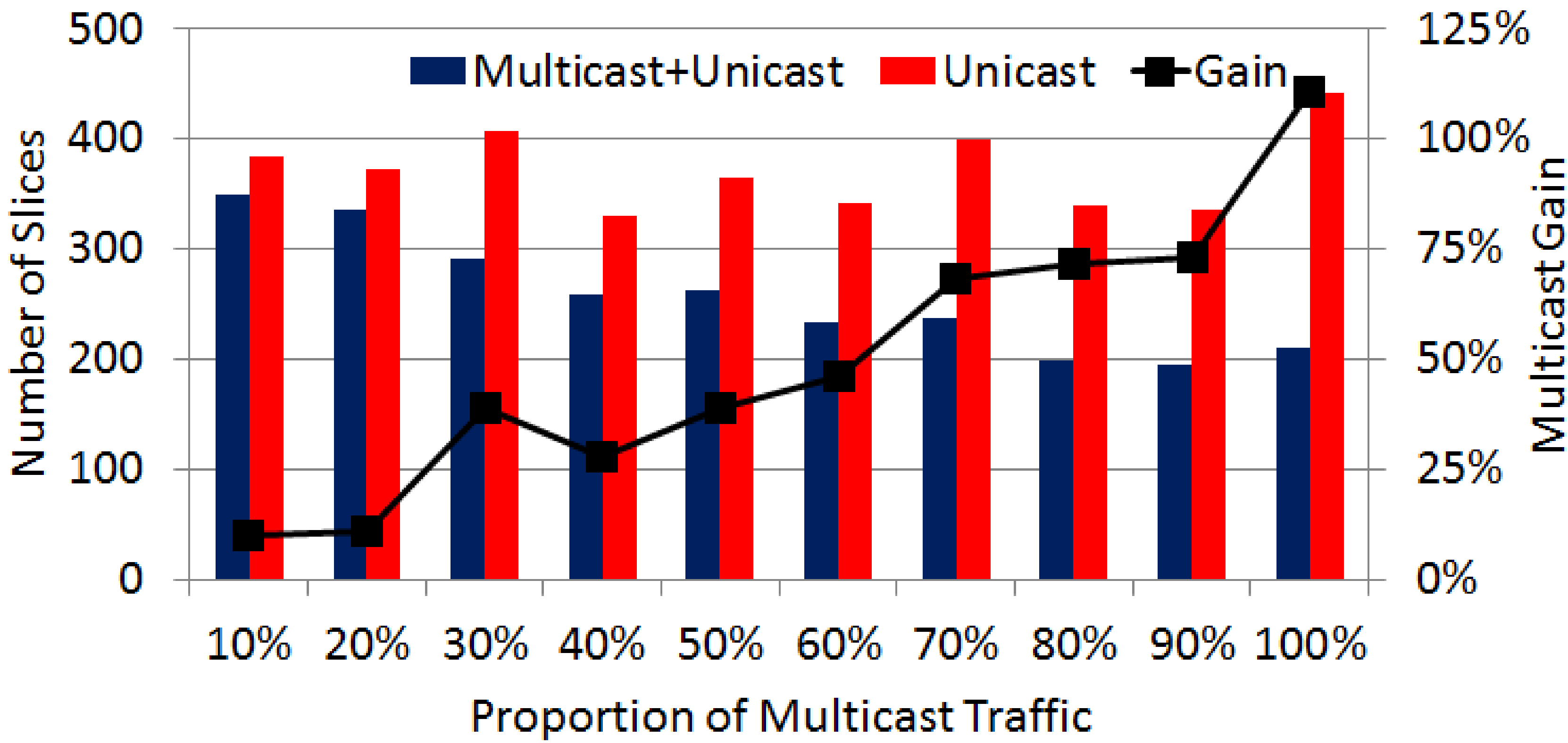
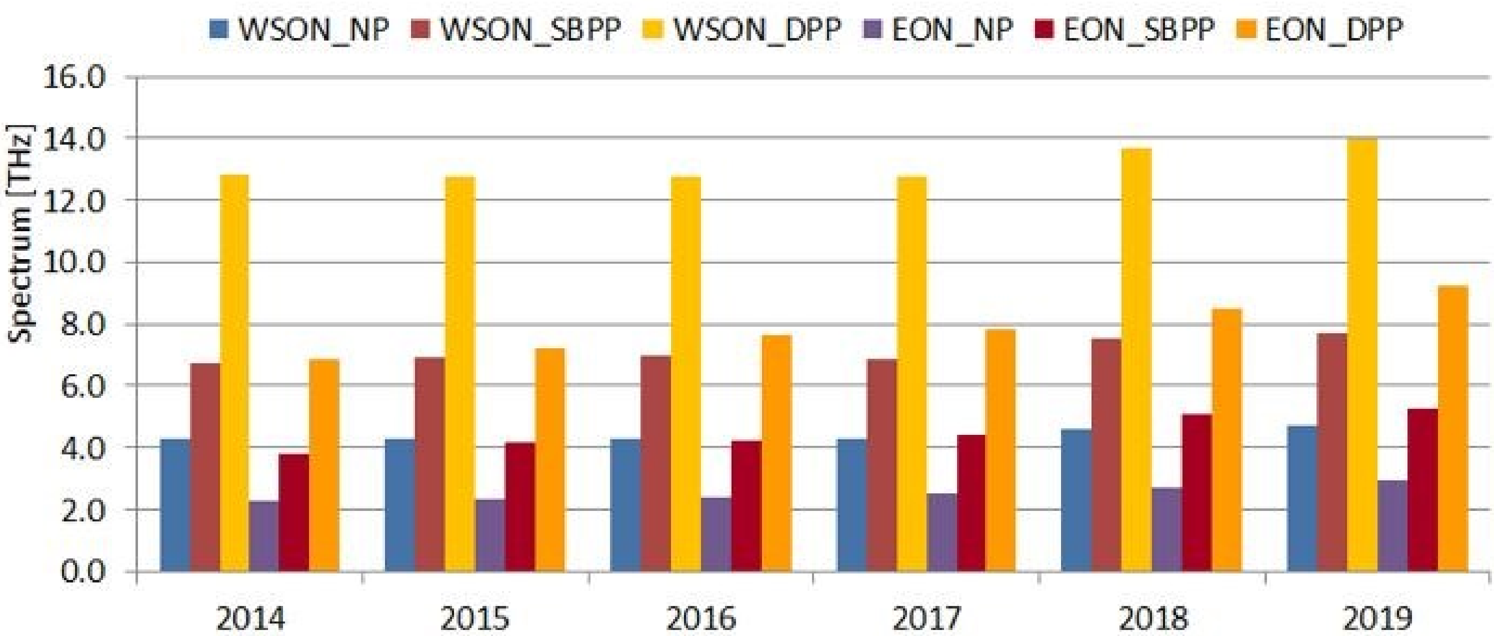
Benefits of multicasting in EONs



[4] K. Walkowiak, R. Goścień, M. Woźniak, M. Klinkowski, „Joint optimization of multicast and unicast flows in elastic optical networks”, in Proc. Of IEEE ICC 2015.

Comparison of protection methods in optical networks



[14] R. Goścień, K. Walkowiak, M. Klinkowski, J. Rak, „Protection in elastic optical networks", IEEE Network 29 (6), pp. 88-96, 2015.

[15] R. Goścień, K. Walkowiak, M. Tornatore, „Survivable multipath routing of anycast and unicast traffic in elastic optical networks", Journal of Optical Communications and Networking 8(6), pp. 343-355, 2016.

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Main research interest

- Content-oriented, DC-oriented networks
- Optical transmission
- Survivability provisioning
- Modeling and optimization approaches
- Realistic case studies

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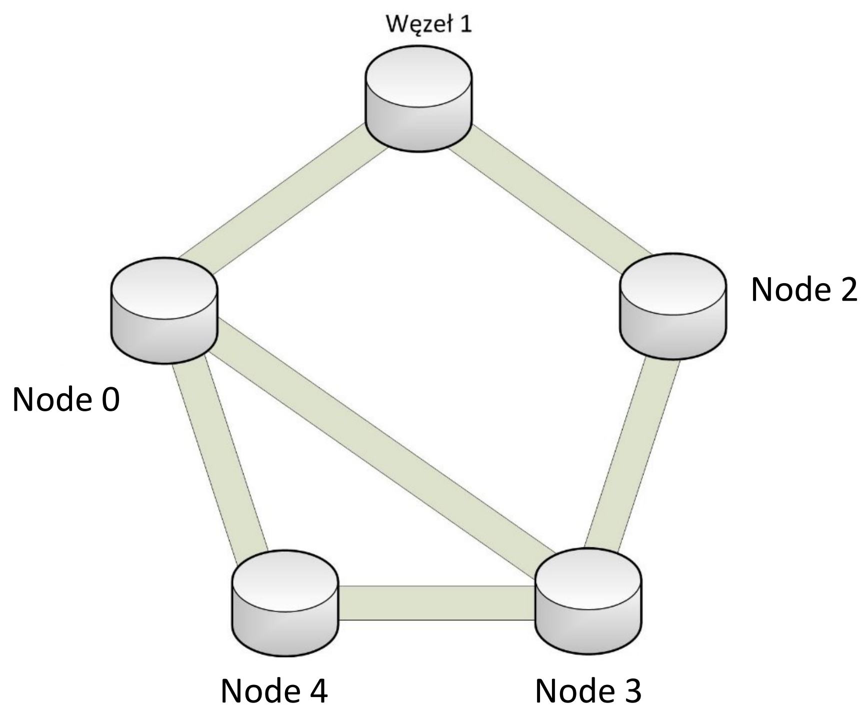
Optimization methods based on machine learning

DEMAND	ROUTE	VOLUME
ANY	2 → DC	200 Gb/s
ANY	3 → DC	360 Gb/s
UNI	4 → 0	150 Gb/s
?	?	?



Traffic prediction

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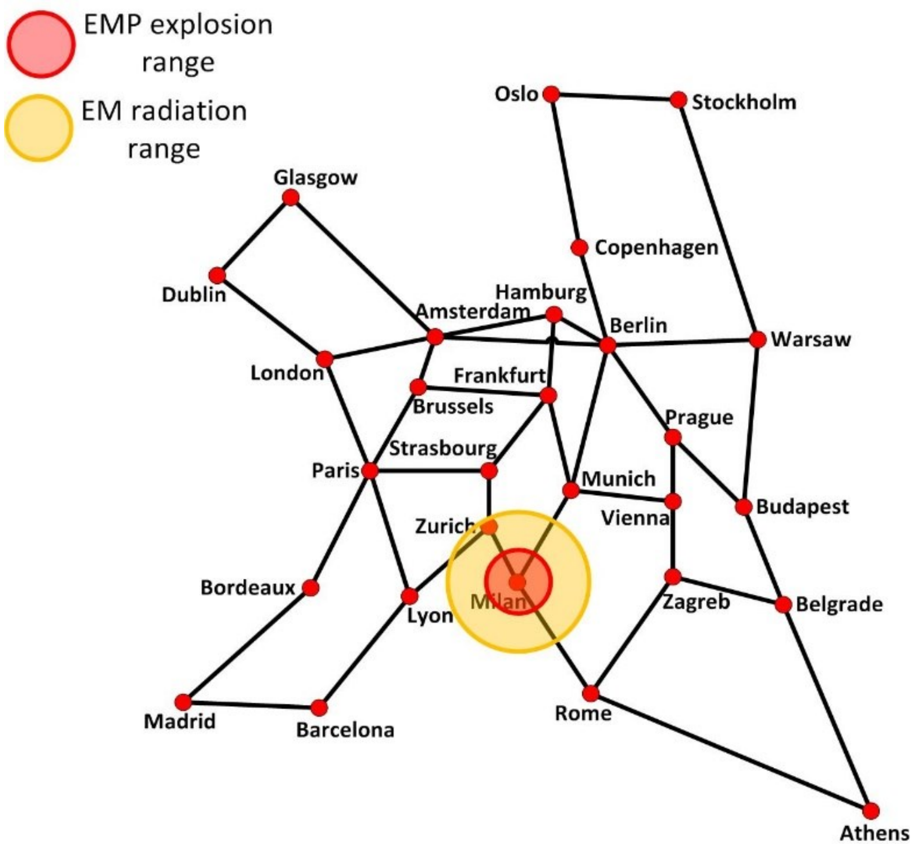
Protection against electromagnetic attacks

- Weapon of mass distruction: explosion and following electromagnetic pulse (EMP)



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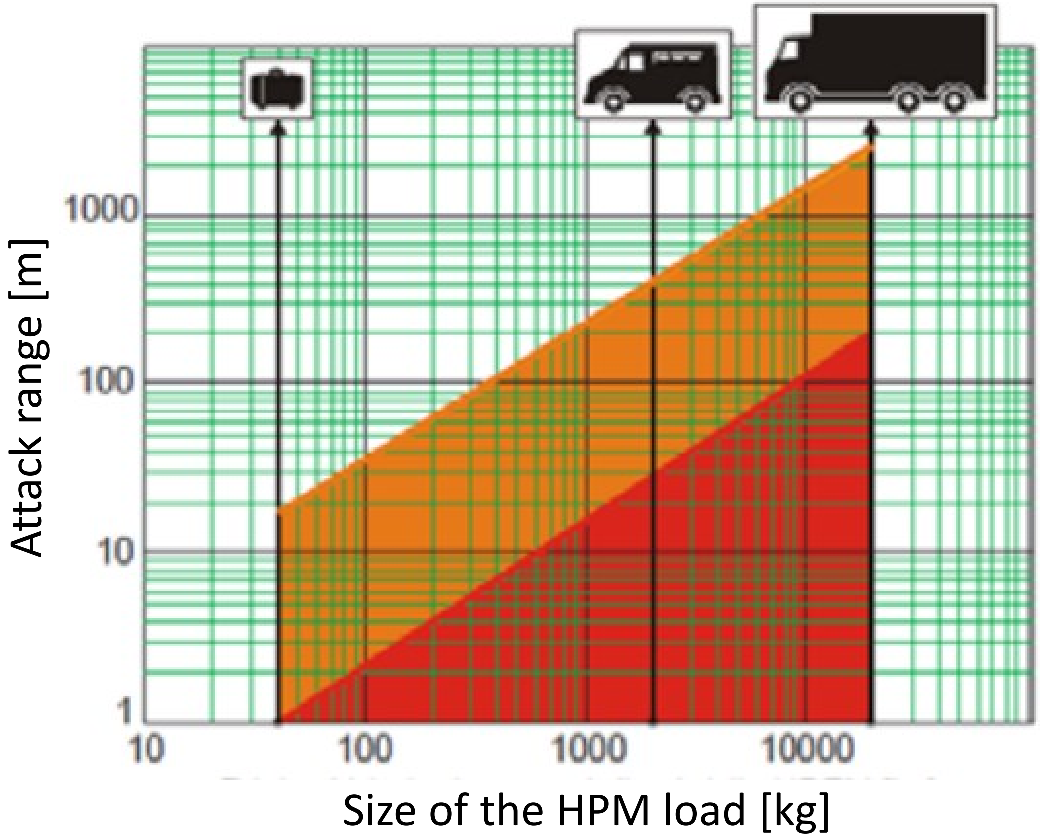
Protection against electromagnetic attacks

- High-power microwave (HPM)



[16] M. Dras, M. Kałuski, M. Szafrańska, „Impulsy HPM – zaburzenia i ich oddziaływanie na systemy – zagadnienia podstawowe", Przegląd Elektrotechniczny 2015 (in Polish).

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Thank you for attention

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